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Preparation and validation of digital maps of geology and slope instability

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Abstract

This paper is concerned with a description of the techniques for the development of digital maps of geology and slope instability. The validation of such maps by field inspection and checking is highlighted. These techniques have been used successfully for the suburbs of the northern Wollongong region of New South Wales. Such maps allow the flexibility of future modifications as additional and or more reliable data becomes available. These maps will facilitate decisions on the planning and management of land use. Currently, 295 cases of land instability have been documented within the study area. The maps are also expected to be useful for the development of reliable hazard and risk assessment procedures.

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Preparation and validation of digital maps of geology and slope instability

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ABSTRACT: This paper is concerned with a description of the techniques for the development of digital maps of geology and slope instability. The validation of such maps by field inspection and checking is highlighted. These techniques have been used successfully for the suburbs of the northern Wollongong region of New South Wales. Such maps allow the flexibility of future modifications as additional and or more reliable data becomes available. These maps will facilitate decisions on the planning and management of land use. Currently, 295 cases of land instability have been documented within the study area. The maps are also expected to be useful for the development of reliable hazard and risk assessment procedures.

1 INTRODUCTION

1.1 Geographical setting

Wollongong is situated on the east coast of Australia approximately 80km south of Sydney (figure 1). The city of Wollongong, with a population of approximately 300,000 people, including its northern suburbs, is a major urban centre on the south coast of the state of New South Wales.

The city is nestled in a narrow triangular coastal plain flanked on the east by the Pacific Ocean and on the west by the steep slopes topped by sandstone cliff lines which together comprise the Illawarra Escarpment. The Wollongong City Council administers an area of 715 square kilometres which includes a highland plateau area to the west of the escarpment and the escarpment itself which grades downwards to the east into the terraced lower slopes. The southeastern and southern margins of the district comprise a coastal plain.

It is estimated that about 100 houses have been destroyed since the turn of the century by land instability. As well as affecting suburban areas, landslides affect the major road and rail transport routes which link Wollongong to Sydney and other regional centres.

1.2 The study area

The area of interest encompasses the northern suburbs of the WCC area, extending from Helensburgh in the north to Mount Kembla and Cordeaux Heights in the south. Within these confines, specifically, the study area comprises the east facing slopes of the Illawarra Escarpment extending down to where these slopes meet the sea and or the coastal plain.

The most useful, accurate and convenient map scale suitable for the needs of this research project is a 1:4000 scale. Accurate computer generated topography and cadastre is readily available from the New South Wales Government Department of Conservation and Land Management. Individual maps sheets at this scale cover an area of 7.5 square kilometres, 3000m east-west by 2500m north-south. The study area is covered by 33 of these 1:4000 map sheets (figure 2).

2 DEVELOPMENT OF HILLSIDE AREAS - THE HAZARDS AND CONSEQUENCES

2.1 Types of slope instability

Past and present sites of suspected land instability, numbering 295, have been mapped within the northern suburbs of the Wollongong City Council (WCC) area. The individual sites of instability vary in size up to a maximum area of about 1800 square metres.

On the basis of the classification proposed by Varnes (1978), various types of instability have been obsereved. These types include rock falls, rock topples, debris falls, debris slides, debris avalanches, soil creep, earth slumps and earth flows and complex combinations of the above. The most common being the debris slump.

Borehole inclinometer monitoring of the subsurface profiles of numerous landslides has revealed a variety of styles of movement within the study area. Block movement of the overlying colluvium with shear movement occurring over a thin band (the minimum increment measured by the inclinometer is 0.5m) at or near the colluvium-bedrock interface is most common within the landslide mass (figure 3). However, this basic style is more often than not superimposed upon by further components of movement. Two or more different depths of shear movement within a colluvium mass have been observed. Block movement with shearing at depth (up to 17.5m) with an apparent inclination uphill of the sliding mass between a depth of 10.0 to 2.0m has been recorded at one site(the borehole is located in the head area of the landslide). Creep movement has also been recorded at several locations extending down to a depth of up to 8.0m. At one site 16mm creep over the period November 1990 to January 1996 has been recorded. Creep type of movement often seems to be superimposed upon a block style of movement.

2.2 Other hazards in the study area relevant to land instability

Rainfall represents one of the most important natural hazards affecting the WCC area. Average annual rainfall is approximately 1100mm but there are many intense rainstorms. In one instance, at Wongawilli, a rainfall of 803mm was recorded over 48 hours to 9.00am 18 February 1984 (Shepherd and Colquhoun, 1985) These extreme rainfall events often trigger landslides and other types of slope instability particularly if antecedant rainfall is significant.

With such high levels of rainfall the flooding and associated scouring of local watercourses is another hazard affecting the WCC area. Associated scouring and slumping of adjacent land along the creek banks is a common problem. In most cases the instability of banks is only localised, however long term effects can be severe. Significant instances of instability of this type have been included in the land instability mapping phase of this project.

Underground coal mining has and continues to be a major industry within the Wollongong area. Collieries dot the face of the escarpment and the plateau to the west. Mining is now prohibited within zones that would affect, by way of mine subsidence, the escarpment or residential land on the eastern slopes of the escarpment. However, there were no such controls in the past. Many early mines accessed the coal seams from drives directly off the slopes of the escarpment. Hence, mine subsidence has affected of the sloping areas of the escarpmen.

2.3 Geological Setting and its importance

The Sydney Basin geological complex comprises a basin sequence of dominantly sedimentary rocks extending in age from approximately Middle Permian to at least Middle Triassic. The study area lies on the south eastern margin of the Sydney Basin (figure 1).

The geological bedrock sequence of the Illawarra district is essentially flat lying with a low angle dip, generally less than five degrees, towards the northwest. This gentle northwesterly dip, whilst superimposed by relatively minor syn-depositional and post-depositional structuring (folding and faulting) is a result of the relative position of the district on the southeastern flanks of the Sydney Basin (figure 1). Normal faulting within the Illawarra area is common, although the fault throws infrequently exceed 10 metres. The structural geology of Wollongong, Kiama and Robertson, mapped on 1:50000 sheets, has been discussed in detail in Bowman (1974).

The geological units encountered within the district, in ascending order, include the Shoalhaven Group, the Illawarra Coal Measures (locally including intrusive bodies collectively known as the Gerringong Volcanic facies), the Narrabeen Group and the Hawkesbury Sandstone (figure 4). The geology of these units has been discussed at length in several previous publications such as Bowman (1974) and Herbert and Helby (1980).

The Illawarra Coal Measures contain numerous economically significant coal seams. Of these, the most notable are, in descending stratigraphic order, the Bulli Seam, the Balgownie Seam, the Wongawilli Seam and the Tongarra Seam. These coal seams have an important influence on the local groundwater pressures and flow, and often include thin very weak tuffaceous claystone bands. The presence and location of these coal seams has been considered significant in several cases of land instability.

In most parts of the district, extending from near the base of the upper cliff line to either the waters edge or the coastal plain, the ground surface is covered by debris of colluvial origin. As bedrock exposures are limited, geological mapping in the area is difficult. The colluvium comprises variably weathered bedrock fragments supported in a matrix of finer material dominantly weathered to sand, sandy clay and clay and brought downslope under the influence of gravity. These processes, which are broadly referred to as land instability, have a natural history which extends back to the Quaternary period.

2.4 Maps of geology and slope instability

Published geological maps which include the Wollongong area are tabulated in Table 1. Whilst this list is not exhaustive, it does include the most current maps. Other, larger scale maps covering smaller areas, are available such as Hanlon 1956, Adamson 1974, Coffey and Partners Pty Ltd 1985, and Pitsis 1992 etc.

SCALE	TITLE	DATE
1:250,000	Wollongong Geological Series Sheet 51 56-9 NSW Dept Mines	1966.
1:100,000*	Wollongong - Port Hacking Geological Series Sheet 9029-9129 NSW Department Of Mineral Resources	1985
1:50,000 *	Wollongong Geological Series Sheet 9029-11& 9028-1&1V NSW Department of Mines	1974.
1:25,000 *	Geology & Natural Slope Stability, in the City of Greater Wollongong in Records of the Geological Survey of New South Wales Volume 14, Part 2	1972
1:25,000	Maps of the Coal Seam Structures in the Southern Coalfield of NSW Australian Coal Industry Research Laboratories Ltd	1989.
1:6336 (see below)	Geology Sheets - City of Greater Wollongong. Geological Survey of New South Wales, Plans 5250-5286, 5545 a thesis by H. Bowman	1970

TABLE 1. Published Geology Maps of the Wollongong Area.
* **Maps based on Bowmans 1:6336 Mapping**

Maps showing areas of slope instability in the Wollongong district appeared in 1942 when Hanlon, then the government geologist, first prepared plans of the area from Stanwell Park to Coldedale. These maps indicated zones of instability affecting the railway and the main road. Subsequently other workers proceeded to document slope instability (State Rail Authority 1964).

Bowman (1972) prepared 16 land instability sheets at a scale of 1:6336 to accompany his geology sheets (Table 1). Bowman's maps, covering the whole of the escarpment area, distinguished six stability zones (essentially unstable, topographically unstable, moderately unstable, less stable, stable land with areas of minor slope instability and stable land). Bowmans Zone 6, essentially unstable land, includes known slip areas.

Golder Associates (1983) prepared a report for the WCC entitled a Guide to suspect Landslip Areas, Stanwell Park to Dapto. In this report, different areas were marked with the following descriptions; recorded past or recent landslip areas, suspect past or potential future landslip, no apparent past movement and no likelihood of future movement. Twenty three 1:8000 WCC building allotment plans were marked up accordingly.

Coffey Partners International (CPI) in 1985 submitted a geotechnical report to the WCC that identified and classified areas of known and potential land instability for the Coledale area. This report distinguished five principal zones with several subgroups. The zones were delineated on the basis of ground slope, underlying geology, form and potential for instability. Known and or suspected slip areas were also shown.

The WCC has its own hazard maps based on a Geographic Information System (GIS). These maps are strictly for internal use within the WCC offices. These plans include and distinguish between numerous local hazards such as known past land instability, potential land instability, landfill and areas subject to flooding.

2.5 The use of existing maps in the region for planning and development of sloping land.

WCC policy 4.05, which relates to the councils acceptance of Building and Development Applications, refers to "building on land which may be subject to subsidence (by which is implied slope instability and/or mine subsidence)". Whilst this policy is currently under review, the policy objective "to ensure the stability of buildings" will remain. To determine whether land is subject to slope instability or not, the council considers, amongst other things, their own hazard maps.

It is clear then, that the accuracy and reliability of these maps is of significant importance.

2.6 The use of existing maps for hazard and risk assessment

For geotechnical workers, the use of existing maps serves to place given locations within their regional context, usually at the early stages of an investigation. Preliminary desktop overviews of a study area, during which geological and slope instability maps are used, provides 'factual' material that will be used to help develop a geotechnical model whilst assisting with the focusing of the needs for the geotechnical investigation.

Maps of slope instability allow workers to gain a clear picture of potential slope instability hazards of the area and will assist with planning investigations and carrying out risk assessments.

3 IMPORTANCE OF DEVELOPING NEW MAPS

3.1 Limitations of existing maps

Previous maps were based on limited information and the quality of the base maps was not as high as it is today. Existing geological maps of the Wollongong area (Bowman 1972) are the result of field work carried out in the late 1960's and early 1970's as well as interpretations of mapping carried out by earlier workers.

Bowman(1972) acknowledged scale inaccuracies, map sheet boundary mismatches of an inch or more, and inaccurate contours on the base maps (Illawarra Planning Authority plans and others based on Metropolitan Water Sewerage and Drainage Board plans) for his work. However, these base maps were the only ones showing the required detail and he had to use them for the geology and land instability mapping.

The map scales at which most geological maps have been prepared limit their use for geotechnical site investigations of relatively small areas of land. Bowmans maps, at a scale of 1:6336, are at a scale that is useful for site investigations. However, the base map inaccuracies outlined above and metrication of map scales, limit the application of Bowman's work in providing an up-to-date regional context.

The areas of instability shown on the maps prepared by Hanlon, Bowman, Golder Associates and CPI are rarely referred to elsewhere in their accompanying reports. Hence, information regarding the areas of instability must be rediscovered at every map consultation. Frequently, such information becomes buried in the libraries of the geotechnical consulting firms.

3.2 Availability of additional information

Twenty five years have lapsed since the last major geological mapping exercise has been carried out within the northern suburbs of Wollongong. Due to the location of the study area within the Southern coalfield and the intensity of land instability within the region an enormous pool of additional geological and geotechnical information has been collected over the last quarter century.

Recent advances in cartography, in particular that of computer generated mapping technology and computer based geographic information systems (GIS), allows current geological and slope instability map preparation to be of truly professional quality. GIS packages allow the full integration of individual map components with database management systems.

Pitsis(1992) prepared two 1:4000 scale geological and slope instability maps of the Stanwell Park to Coalcliff area. The mapped geological boundaries were based on field mapping and interpretation of numerous State Rail Authority(SRA) geotechnical boreholes. Included on these two maps were fifty four cases of slope instability. In addition to these two large scale maps, a 1:25000 scale map, extending from Stanwell Park in the north to Mount Kembla in the south, showed 164 (including 54 sites on 1:4000 sheets) sites of slope instability. The sites were numbered on the plans and a tabulated summary appeared in the text. It should be noted that Pitsis did not use a computer based approach, and therefore the flexibility and convenience of updating such maps is very limited.

3.3 The need for future flexibility

The importance of a valid geotechnical model, including the extent and accuracy of the geological information on which it is based cannot be overstated. A geotechnical model will always be limited by the availability of the information. Moreover some of the information may be of poor quality (ie not surveyed to a regional survey grid) and/or may prove to be inaccurate and therefore cannot be used. It is therefore clearly necessary to update geological and land instability information as more information becomes available and as the accuracy of the information is further improved. Some existing information may, in the course of time, be found to be inaccurate or unreliable. Ultimately the ability to incorporate new information and then re-produce the updated geotechnical model is an important tool for improving the understanding of an area.

A flexible approach to current data compilation, mapping, map generation, whilst allowing for future modification is extremely useful and confirms the viability and resourcefulness of a computer based Geographic Information System package. The maps are easily reproducible at a scale appropriate for any investigation. It must be mentioned that the true scale of the maps is 1:4000. At any larger scale, some accuracy will be lost. The use of a metric scale, allows easy scale changes with simple photocopying.

The maps prepared with the GIS package have been designated the Geotechnical Landscape (GL) map series, version 1. A version number is included, for each map sheet, to allow for future modifications (versions 1+).

4 MAIN TECHNIQUES USED IN THE PREPARATION OF NEW GEOTECHNICAL LANDSCAPE MAPS

4.1 Stages in the preparation of maps

All of the mapping work undertaken during this research was integrated with a GIS package. A schematic outline of the processes is shown in Figure 5.

4.2 The GIS computer package

The WCC, as the major sponsor of this project has made some of its computer facilities available for this project. The council uses Genasys II Australia Pty Ltd's Genamap GIS application running on various HP platforms in combination with an Ingress database (Ganin, 1974). The GIS system employs cadastral information as the central spatial reference. The contours have been supplied by the Central Mapping Authority (CMA) via the Land Information Centre at Bathurst and have been determined photogrammetrically at a 2m contour interval. International Survey Grid, Australian Map Grid and latitude longitude coordinate systems are available.

4.3 Use of the GIS package

The GIS computer package is an integrated series of computer programs that allows digital manipulation of spatial data. Understanding and operating any GIS package requires professional training and considerable skill. The WCC GIS is for internal staff use only. Maps may be produced and sold to the public at commercial rates.

The WCC GIS section manages and manipulates vast quantities of spatial data as is required for council operations. The vast databases of the GIS are replacing old systems whereby different departments maintained their own maps.

GIS treats spatial data in digital format. A GIS breaks maps down into components, ie contours, creeks, cadastre, geology and land instability etc which can individually be treated as layers on any map, to be printed at any scale a user may require. Hence any map can call for several of the "layers" available within the GIS to be superimposed on each other. Map construction is completed by the experienced staff in the GIS section.

As part of a larger research project, four additional layers within the GIS have been created by the author. These are; borehole locations with an attached Ingress database, GEOWELLS, major fault locations, FAULTS, geology, STRATIGRAPHY, and land instability with an unattached MS Access database, LANDINST. For the time being it has been decided to have the LANDINST database as one which is separate from the GIS. It is being set up on a microsoft package.

4.4 Borehole database- GEOWELLS

The initial phase of this work was to establish a borehole database upon which the geological mapping could be commenced. This database was required as bedrock outcrops are scarce and of limited extent within the study area, due to the colluvium cover. Boreholes drilled (both prior to and after Bowmans late 1960's research) in an area between the coastline and two kilometres west of the escarpment were reviewed for suitability. The boreholes were primarily coal exploration boreholes researched from the libraries of mining companies such as BHP, KCC and Shell. In addition some boreholes drilled as part of geotechnical investigations of land instability within the area have been incorporated in the database.

Boreholes considered as suitable for inclusion in the database contained the following; useful stratigraphic information (that is intersecting at least one stratigraphic horizon), accurate survey information (say Integrated Survey Grid - ISG - coordinates and reduced ground surface level to Australian Height Datum- AHD) or site plans allowing such coordinates to be determined from the 1:4000 scale plans. This information has been entered into an Ingres database within the GIS system. The database contains 160 boreholes. When plotting a map for any given area, if the database is referenced, a labelled symbol has been plotted at the location of any borehole.

4.5 Structural geology - FAULTS

The Australian Coal Industry Research Limited (ACIRL) has compiled a series of 1:25000 Structure Contour plans showing structuring (folding and faulting) recorded at the level of the Bulli and Wongawilli coal seams. This map series represents a compilation of mine record tracings at a uniform datum (10000 metres below AHD). Major faults from this map series with throws in excess of 10m have been digitised and stored within the GIS system as a layer to be plotted when required. These faults have been used to subdivide the project area into eight fault confined discrete geological blocks. Whilst the geology in each block is similar to the next, a change in relative levels (>10m) of the geological sequence occurs between each due to the relative vertical displacement across the fault(s). The maximum relative displacements are as high as 70m and faults with displacement less than 10m have not been included.
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4.6 Land instability database-LANDINST

All known cases of land instability within the subject area have been mapped on the 1:4000 sheets and subsequently digitised and stored within the GIS system. Each case of instability has been assigned a specific four digit site reference number. The reference number and the outline of the instability appear on the appropriate map area if the land instability data is referenced by the GIS when the map is being prepared.

In addition to the digitised land instability data, a Microsoft Access (v2.0) database is being compiled. This database references each of the 290 cases of land instability with such data fields as:

- i) site reference number (individual 4 digit code)
- ii) grid position to approximate centre of main scarp
- iii) size L(m down slope), W(m across slope)
- iv) type of instability (with list of 12 to select from)
- v) slide geometry
- vi) investigation type (with list of 5 to select from)
- vii) name of consultant
- viii) reference to report or data source
- ix) recurrence dates reported for site
- x) failure material type
- xi) shear strengths (bedrock unit, colluvium, back analysis, lab)
- xii) site status
- xiii) remedial works
- xiv) houses damaged
- xv) houses destroyed
- xvi) persons injured
- xvii) persons killed
- xviii) estimated cost of damage
- ixx) estimated cost of remedial works

The mapped record of instability represents a compilation of works (such as site plans, photographs and descriptions) prepared by other workers. It must be noted here that drafted margins of possible land instability are time-dependant features and must be subject to periodic review. Hence the drafted extent of possible land instability as shown in the maps should be considered as depicting only a stage in the development of landsliding or hillslope movement.

4.7 Geological Mapping

The 1:4000 geological maps compiled during this project have been produced using an integrated series of techniques including;

i) computer modelling,

ii) field mapping, and,

iii) inference from existing maps.

Each of these techniques is discussed below.

Computer Modelling.

A relatively dense cluster of boreholes with sufficient stratigraphic detail was available in the southern most discrete fault confined block covering five of the 1:4000 map sheet areas, N6, N7, O5, O6 and O7. Hence this area was used to trial computer modelling of the escarpment geology using the GIS package. Contour information covering these five 1:4000 map sheets was, however, less accurate (prepared at a scale of 1:10000) than for the rest of the study area so the benefits of this method of modelling were limited.

Computer generated stratigraphic surfaces were produced by passing a surface through the relevant formation tops from each borehole site within the fault isolated block. This technique involved only interpolation between known real points. The technique used in the GIS system includes krigging then triangulated irregular network (TIN) modelling. Three horizons, the base of the Stanwell Park Claystone, Base of the Bulli Coal and the base of the Wongawilli Seam were contoured by this method

Each contoured stratigraphic surface was then examined on graphical workstations by an array of cross sections whereby an extrapolated or interpolated intersection point (subcrop) with the natural surface of the escarpment was digitised. The cross sections were set out approximately perpendicular to the escarpment at 500m centres (figure 6).

The digitised (subcrop) points were then plotted out in plan form. The points provide a guide to stratigraphic positioning at various intervals along the escarpment. For the three surfaces, each consecutive point is joined by an outcrop/subcrop line typically running parallel or subparallel to the contours producing a computer-generated geological map.

For the remaining study area, where such computer modelling was not possible, simple cross sections based on borehole stratigraphy were generated. Twenty two cross sections were prepared using the GIS package. Stratigraphic profiles were manually generated and extrapolated/interpolated to the various intersection points (subcrops) with the natural surface of the escarpment.

Geological Field Mapping

Geological mapping within the district is severely limited due to the lack of outcrop and limited access due to the frequent steepness of the terrain and vegetation cover. However, the standard practice of geological mapping has been undertaken where conditions permit. Field mapping was carried out directly onto the 1:4000 map sheets, using the CMA orthophoto (contours superimposed onto a dyeline black and white photograph) sheets to assist field positioning.

Sections have been mapped along scouring watercourses and roadside cuttings. Excellent bedrock exposures exist in man made rock cuttings adjacent to Illawarra South Coast Railway Line, upper sections of Mount Ousley Road and the natural coastal cliffs between Garie and Thirroul.

Inference

Numerous small areas have been the subject of detailed geotechnical investigations, which often included some mapping work. For example Morrison Avenue was studied by Longmac Associates and Woonona Heights which was studied by Coffey Partners International, both on behalf of the Wollongong City Council. Where confidentiality permits (such as where geotechnical reports have been commissioned by the WCC or where open information policies exist as at times in the Roads and Traffic Authority - RTA or the State Rail Authority -SRA) such geotechnical mapping has been incorporated in this project. Whilst such work may itself be based on Bowmans work, it is frequently refined to the local area often with supporting subsurface investigations by way of test pit excavations and shallow auger/core drilling etc. This level of work has often been used as the first or second (if borehole data is available) stage of mapping in an area.

In areas where no field mapping and or borehole data was available the position of geological boundaries have been inferred on the basis of either previous mapping by other workers and/or topography shown on the 1:4000 sheets.

5 VALIDATION OF MAPS AND IN PARTICULAR CHECKING THROUGH FIELD INSPECTIONS

5.1 Validation of borehole data

The borehole database contains stratigraphic information from 160 boreholes, including geographic data locating each hole. The reprorted ISG coordinates and ground surface level to AHD(m) have been compared from the log sheets to the relative level of the mapped point to confirm a data match. If the reported survey relative ground level of the borehole collar did not match that of the mapped point (within 4 metres) then the borehole data was not used. Similarly if the surveyed point appeared to be inaccessible or out of character with the log sheet, then the borehole was not used. Such checking invalidated the use of an additional 65 boreholes and the remaining 160 boreholes were actually used for mapping. Considerable judgement concerning geological interpretation was required, especially with the older boreholes, when determining the stratigraphic profile from the recorded log.

5.2 Fault mapping

As noted above, faults used in this mapping exercise have been compiled by ACIRL(1989) from mine workings in the Bulli or Wongawilli coal seams. Only major faults with throws in excess of 10m have been included.

During the geological mapping work the faults have been shown as vertical. The faults are shown at the surface in the same position as which they have been encountered at depth in the Bulli/Wongawilli Coal seams, unless field evidence suggested otherwise (ie Scarborough fault has been shown as non vertical).

Existing geological maps show several faults which correspond to topographical features, typically, valleys (such as the Mount Pleasant and Scarborough Fault of Bowman 1972). Some of these mapped faults do not correspond with the ACIRL detail (the Mount Pleasant fault). Hence some of the faults shown differ from those mapped previously.

5.3 Geotechnical reports

Much of the geological mapping background information, including interpretation of stratigraphy encountered in geotechnical boreholes has been researched from geotechnical reports prepared by private consulting firms. This geological information arises from detailed investigations focusing on relatively small areas.

On occasion, placement of a small site within the regional context can be way off. A recent stability investigation in the Byarong Creek valley, south of Mt. Kiera, interpreted a coal seam encountered in test pit excavations as the Wongawilli Seam, on the basis of subjective judgement alone. Regional mapping, supported by the well data base and other geotechnical investigations in the adjoining area suggest the coal seam to be the Unanderra Seam. This represents a stratigraphic mismatch of some one hundred metres which can be attributed to lack of knowledge or poor judgement, or both.

5.4 Field mapping

Field mapping allowed the direct mapping of geology in many areas where no other information existed. It also allowed the confirmation or otherwise of reported geology and land instability in other areasIn some instances, deeply incised water courses on the escarpment provided excellent bedrock exposures allowing accurate fixing of the geological sequence.

The computer-generated geological surfaces and subcrops determined from cross sections required some field checking, where ground conditions allowed. This allowed the confirmation of, and where necessary, adjustment of the mapped subcrop to fit surface exposures.

Whilst an altimeter accurate to five feet provided a useful mapping aid, a hand held 1994 model Magellan Global Positioning System did not provide an acceptable level of accuracy on the steep and forested slopes of the escarpment.

6 THE USE OF GENERATED MAPS FOR THE AREA

6.1 The use of maps for planning and management of land use

The Geotechnical Landscape (GL) series maps are a significant improvement over pre-existing geological and land instability maps that are available to geotechnical workers. Similarly, they represent an improvement over the geological maps available within the council. Based on the inclusion of considerable new data and the care employed in checking its reliablity, confidence can be expressed that the GL maps are an improvement over the council hazard maps, in relation to land instability.

The accuracy of the GL maps should allow workers to reliably place any site within its local geological and land instability context. This will allow future geotechnical investigations to become more focussed and precise at earlier stages of the investigation. Ultimately this will allow a more thorough investigation, and hence a better understanding of the site.

6.2 The use of maps for incorporation in hazard and risk assessment procedures

Now that accurate maps of geology and land instability exist for the study area, hazard and risk assessment procedures can be developed. The land instability data base will form an integral aspect of developing these procedures.

The GIS package allows relatively simple access to the spatially orientated statistical data of the map coverage. Statistics regarding areas and relative percentages of geological subcrop, areas affected by land instability of different types, and various combinations of these aspects will be available. The land instability database will provide access to both spatial and temporal aspects of land instability. The temporal aspect is incorporated to the extent that the recurrence of instability at any site is a field for each record within the database. Access to this statistical data will enable a more quantitative assessment of risk to be achieved. Developing such methods is the next task.

7 CONCLUSIONS

The paper highlights the importance of a valid geological model, including the extent and accuracy of the information on which it is based. Ultimately the ability to incorporate new information and then re-produce the updated geological model is an important tool for improving the understanding of an area. It is for these reasons that a flexible approach is extremely useful and confirms the viability and resourcefulness of a GIS for such a project.

A reliable and relatively accurate geological framework has been developed and an up to date land instability database has been compiled. The borehole and land instability databases canbe updated when necessary. This will increase the accuracy and reliability of the maps in the future. Field mapping has served to validate the maps produced.

The project can now move forward with the aid of the GIS package to collect statistical data regarding the geology and land instability. This will assist in the development of a quantitative risk assessment procedure for land instability.

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